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Northern Appalachians: Avalon and Meguma Terranes

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1 Introduction

Possible correlatives of the West African Orogens in the northern Appalachians occur along the eastern seaboard of North America, where they comprise the Avalon Composite Terrane and the Meguma Terrane. The Avalon Composite Terrane is defined by the presence of a lithostratigraphically correlative, subaerial-shallow marine, Cambro-Ordovician overstep sequence containing an Acado-Baltic fauna (Keppie 1985). In general, these Cambro-Ordovician rocks are only preserved in outliers, so overstep relationships are inferred from their close lithostratigraphic similarity. Where the Cambro-Ordovician rocks have been removed by erosion, it is possible to use the presence of the lithostratigraphically correlative, Silurian-Gedinnian overstep sequence containing the distinctive Rhenish-Bohemian fauna (Boucot 1975). By this definition, the Avalon Zone includes New England southeast of the Hope Valley-Bloody Bluff fault zone; Maine and New Brunswick south of the Turtle Head and Honeydale faults; most, if not all of northern Nova Scotia, and Newfoundland east of the Dover-Hermitage fault (Fig. 1). Terranes with Late Precambrian rocks northwest of these faults, such as the Hope Valley and Nashoba Terranes (O'Hara and Gromet 1985), have not been included in the Avalon Composite Terrane because the distinctive, Avalonian, Early Paleozoic rocks are absent. Should future work show that the Early Paleozoic overstep sequence was present before erosion, these terranes would need to be added to the Avalon Composite Terrane. In the Avalon Composite Terrane, the Early Paleozoic rocks rest unconformably - disconformably - conformably upon a variety of Late Precambrian igneous rocks and turbidites over Middle-Late Proterozoic or older metasediments and gneisses.

Contrasts in the late Proterozoic stratigraphy led to the subdivision of the Avalon Zone into several late Proterozoic terranes (Keppie 1985, 1988). The main terranes were: (1) Cape Breton Terrane: a cratonic magmatic arc; (2) Antigonish Highlands and Cheticamp Terranes: inter-arc basins floored by oceanic lithosphere; and (3) Cobequid Highlands Terrane: a cratonic magmatic arc. However, new data have allowed lithostratigraphic correlations to be made across northern Nova Scotia which suggest the presence of just one terrane consisting of alternating basins floored by thinned continental lithosphere (rather than oceanic lithosphere) and horsts (Keppie and Dallmeyer 1989b). These are interpreted as a magmatic arc-intra-arc rift complex that lacks oceanic components.

Similarly, Barr and Raeside (1986) subdivided Cape Breton Island into four, apparently contrasting, tectonostratigraphic zones or terranes, designated from southeast to northwest: Southeastern, Bras d'Or, Highlands and Northwestern Highlands. They defined these terranes as follows: (1) southeastern Terrane: Late Precambrian volcanism and plutonism followed by Cambro-Ordovician rift basin sedimentation and minor volcanism: (2) Bras d'Or Terrane: gneissic basement overlain by platform sedimentary rocks (George River Group) intruded by mainly Late Precambrian and Ordovician (?) granitoid rocks: (3) Highlands Terrane: gneissic core flanked by low grade sedimentary and volcanic rocks of probable Precambrian age intruded by diverse Precambrian-Carboniferous plutons: and (4) Northwestern Highlands Terrane: gneissic basement intruded by varied plutonic rocks including anorthosite, syenite and gabbro. Barr and Raeside (1986) inferred the Southeastern and Bras d'Or Terranes to be part of the Avalon Terrane, although Barr et al. (1987) correlated the Bras d'Or Terrane

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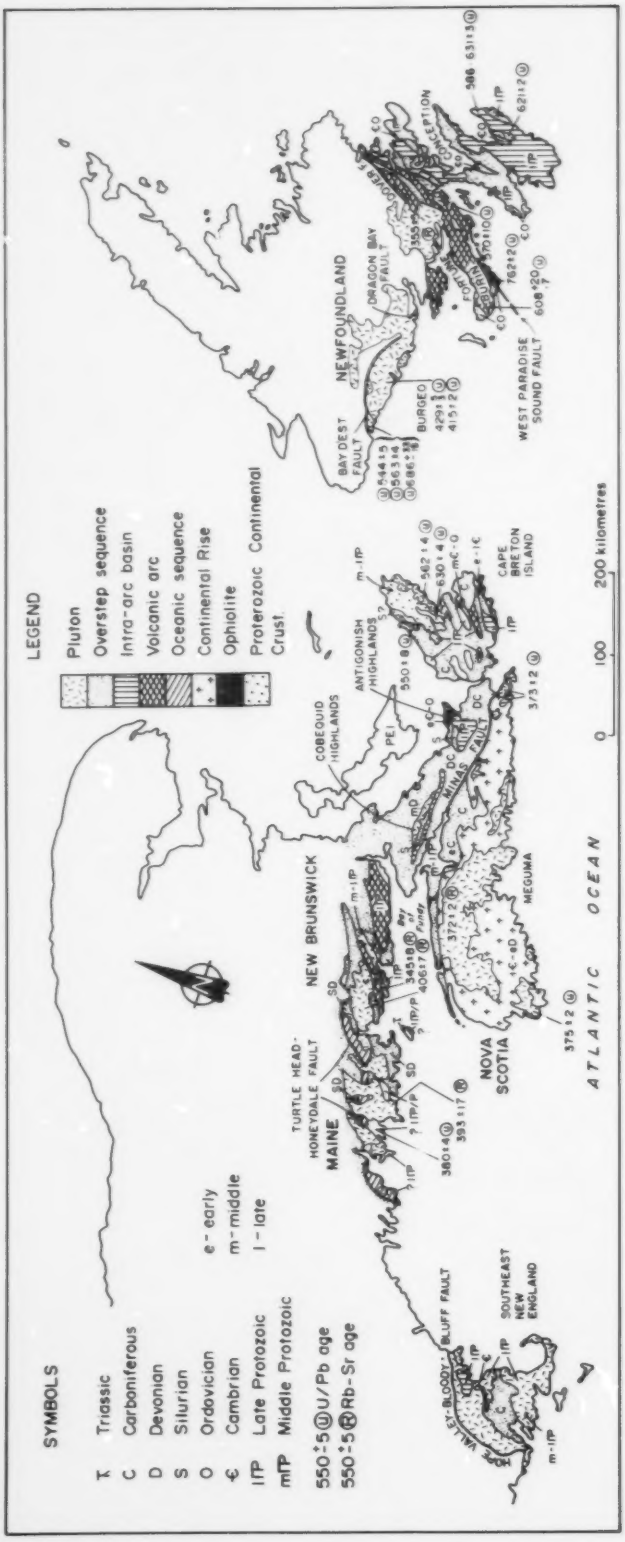

Fig. 1. Tectonic map of the Meguma Terrane and Avalon Composite Terrane in the northern Appalachians. The boundary between these terranes is the Minas Fault. The northern boundary of the Avalon Composite Terrane is the Hope Valley - Bloody Bluff - Turtle Head - Honeydale - Dover Fault system

with the Gander Terrane. The Highlands Terrane was correlated with the Gander Terrane or the outboard edge of the Piedmont Terrane in Newfoundland, and the Northwestern Highlands Terrane was inferred to be an outboard part of autochthonous, Grenvillian North America (Piedmont Terrane of Williams and Hatcher 1983; North American Terrane of Keppie 1988). However, other data suggest that Cape Breton Island, like mainland northern Nova Scotia, represents a single Avalonian terrane. Keppie (1979, 1982) and Currie (1987) have shown that the felsic and mafic gneisses in the Northwestern Highlands "Terrane" may be traced through both the Highlands and Bras d'Or "Terranes". In addition, the Precambrian platformal unit characterized by the George River Group (Keppie 1979) in the Bras d'Or "Terrane" may be traced into the Highlands "Terrane" as the McMillan Flowage Formation (of Barr and Raeside 1986) and Cape North Group (of Macdonald and Smith 1980). Also, Late Proterozoic volcanic rocks and the Cambro-Ordovician overstep sequence are present in both Southeastern and Bras d'Or "Terranes", while pebbles containing Cambro-Ordovician and Silurian fauna typical of the Avalon Composite Terrane have recently been found in a Lower Carboniferous conglomerate derived from the Mabou Highlands lying within the Highlands "Terrane". Furthermore, published geochronological data show that late Proterozoic-Cambrian and Paleozoic plutons are present across most of Cape Breton Island. The basement beneath the southeastern "Terrane" is not exposed. However, the geochemistry of the late Proterozoic volcanic rocks indicates the presence of continental crust (Keppie et al. 1979). These data suggest that the rocks of Cape Breton Island, rather than representing distinct terranes in an entire cross-section of the Appalachian Orogen as proposed by Barr and Raeside (1986), expose an oblique section of the Avalon Composite Terrane with progressively deeper levels of the late Proterozoic magmatic arc complex cropping out northwestward. That the gneisses in northern Cape Breton Island are not contiguous with the outer edge of cratonic North American basement is indicated on seismic reflection profiles between Newfoundland and Cape Breton Island which show that the top of the Grenvillian basement is at a depth of >10 seconds two-way travel time in the Cabot Strait off northern Cape Breton Island (Marillier et al. 1989).

Ophiolitic rocks are only known in the Burin Terrane within the Avalon Composite Terrane of Newfoundland. The ophiolitic nature of the Burin Terrane contrasts with the continental nature of the neighbouring Fortune and Conception Terranes. However, the present geographical separation between the Avalon Composite Terrane in Newfoundland, Nova Scotia-New Brunswick-Maine, and New England, and uncertainties about their correlation, suggest that it is prudent at present to distinguish them as separate terranes.

South of the Avalon Composite Terrane in Nova Scotia lies the Meguma Terrane which consists mainly of a lithostratigraphically distinct Cambro-Ordovician sequence of turbiditic wacke and slate. These rocks are overlain by shallow marine-continental Siluro-Devonian rocks containing a Rhenish-Bohemian fauna (Boucot 1960) which links it with the Avalon Composite Terrane.

1.1 Terrane Boundaries

In simple terms, the boundary between the Avalon Composite Terrane and the Meguma Terrane is defined by the E-W Minas fault zone which swings into a southeasterly dipping listric fault in the Bay of Fundy (Keppie and Dallmeyer 1987). The Minas fault is overstepped by the Lower Carboniferous Horton Group. In Devono-Carboniferous times these two segments of the fault were dextral transcurrent and W-vergent thrust structures respectively. However, in the Mesozoic these movements were reversed in response to the birth of the Atlantic Ocean. Subsidiary listric faults exposed along the southern coast of New Brunswick display a similar movement history of Carboniferous thrusting followed by Mesozoic normal faulting (Plint and Van de Poll 1982, 1984; Nance and Warner 1986). The southeastern margin of the Meguma Terrane borders on the present Atlantic Ocean.

In general terms, the nature of the northwestern boundary of the Avalon Composite Terrane changes along strike from a vertical fault zone of Late Silurian age in Newfoundland, through a westerly-vergent thrust of Early-Middle Devonian age in southern New Brunswick, to a dextral shear zone with a component of E-vergent thrusting of Late Devonian-Early Permian age in New England (Keppie 1988). In Newfoundland, the Dover-Hermitage fault zone appears on seismic reflection profiles to be a vertical fault which extends through the entire crust (Keen et al. 1986). There is a marked contrast in intensity of deformation across the fault from intense polyphase deformation accompanied by metamorphism which reaches the upper am-

phibolite facies in the Gander Terrane, to milder deformation accompanied by greenschist metamorphism in the neighbouring Avalon Composite Terrane (Dallmeyer et al. 1981a). Hanmer (1981) has shown that the amphibolite-upper greenschist facies ductile strain in the Gander Terrane resulted from sinistral transpression, while Caron and Williams (1988a) inferred that early sinistral transpression in the western Avalon Composite Terrane was followed, adjacent to the Dover fault, by lower greenschist to brittle fabrics resulting from a complex movement history involving dextral shear followed by normal, reverse and dextral displacements (Caron and Williams 1988b). The development of some of the ductile fabrics is constrained between the intrusion of the Cape Freels pluton (Rb-Sr whole-rock isochron age of 414 ± 5 Ma; Bell et al. 1977) and a $^{40}Ar/^{39}Ar$ plateau age of 397 ± 5 Ma on hornblende from gneisses adjacent to the Dover Fault (Dallmeyer et al. 1981a). $^{40}Ar/^{39}Ar$ plateau ages on whole-rock phyllite from the western Avalon Composite Terrane range from 400 ± 10 to 353 ± 10 Ma and are interpreted to closely post-date the metamorphism associated with the development of the cleavage (Dallmeyer et al. 1983). An upper limit on the brittle movements on the Dover-Hermitage fault is provided by the age of the Ackley City Batholith, a stitching pluton (Rb-Sr whole-rock isochron age of 355 ± 5 Ma; Bell et al. 1977; $^{40}Ar/^{39}Ar$ plateau age on hornblende $= 356 \pm 10$ Ma, Dallmeyer et al. 1981a). The northwestern boundary of the Avalon Composite Terrane in southern New Brunswick and Maine is defined by the Honeydale-Turtle Head fault, which has been interpreted as a NW-vergent thrust by Ruitenberg and Ludman (1978), Ludman (1981) and Osberg et al. (1985), although Stewart et al. (1986) infer a SE-vergence from the reflection seismic data. This boundary displaces units as young as Late Silurian and is stitched by several plutons, the oldest of which is dated at 380 ± 4 Ma (Lucerne pluton, Loiselle et al. 1983). In southeastern New England, the northwestern boundary of the Avalon Composite Terrane (Bloody Bluff-Hope Valley shear zone) is a dextral shear zone with a component of easterly-vergent thrusting (Skehan 1983; Rodgers 1985; O'Hara and Gromet 1985). Some of the movements on this boundary are constrained between the 370 ± 7 Ma Rb-Sr whole-rock isochron age of the Scituate pluton (Hermes and Zartman 1985) and the 273 ± 2 Ma U-Pb monazite age and lower intercept, U-Pb zircon age of 276 ± 7 Ma of the Narragansett Pier stitching pluton (Zartman and Hermes 1987).

This review of the Avalon Composite Terrane will focus on its Precambrian-Cambro-Ordovician geological record under the following headings: stratigraphy and paleontology, structure and metamorphism, igneous activity, geophysics, and tectonic interpretation. Other recent reviews include O'Brien et al. (1983), Rast and Skehan (1983), Keppie et al. (1985) and Nance (1986), to which the reader is referred for a more comprehensive treatment, and references therein.

2 Stratigraphy and Paleontology

The stratigraphy of the Avalon Composite Terrane and the Meguma Terrane is summarized in Figs. 2 and 3. The oldest rocks in the Avalon Composite Terrane are represented by ortho- and para-gneiss and amphibolite sheets: the Pleasant Bay and Kellys Mountain Complexes and equivalents in Cape Breton Island, the Great Village River Gneiss and Mount Thom Complex in the Cobequid Highlands of Nova Scotia, and the Brookville Gneiss in southern New Brunswick. A possible lithologically correlative unit of unknown age in southeastern Massachusetts may be the gneiss and schist exposed southeast of the Carboniferous Narragansett Basin.

At present the age of these units is poorly constrained. In New England, the only relevent data come from the Narragansett Pier Granite, which gives an Archean source age (2678 ± 78 Ma) based upon the upper intercept of the chord on the U-Pb concordia diagram (Zartman and Hermes 1987).

U-Pb zircon analyses from a sample of the Brookville Gneiss do not plot on a single chord, which is indicative of several unresolved Pb loss events (Olszewski and Gaudette 1982). However, one analysis of a single, euhedral, clear zircon from the same sample was essentially concordant at ca. 814 Ma. A quartz diorite gneiss believed to be the product of anatexis during the metamorphism yielded U-Pb upper and lower intercept ages of 827 ± 40 and 333 ± 40 Ma, but is based on only two analyses (Olszewski and Gaudette 1982). A Rb-Sr whole-rock isochron for both gneiss lithologies yielded an age of 771 ± 55 Ma. Collectively, these data suggest that the high grade metamorphism of the Brookville Gneiss took place at least 800 Ma ago.*

The Mount Thom Complex has given a poorly defined Rb-Sr whole-rock isochron of 934 ± 82 Ma

* see footnotes on p. 329.

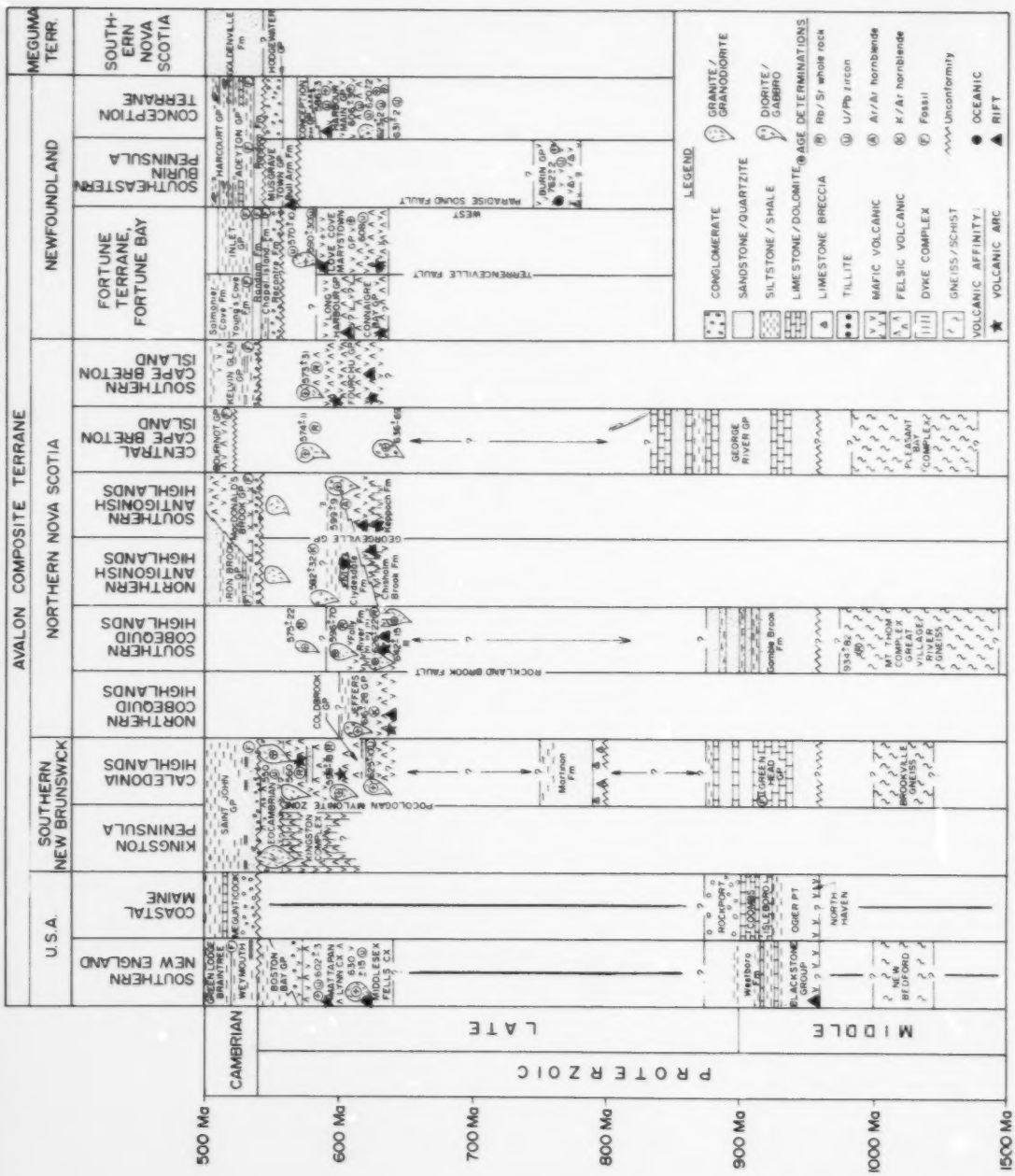

Fig. 2. Precambrian-Cambrian lithostratigraphy of the Meguma Terrane and Avalon Composite Terrane in the northern Appalachians

which may provide a minimum age for the metamorphism (Gaudette et al. 1983, 1984).

The gneisses of the Kellys Mountain Complex have yielded a Rb-Sr whole-rock error chron of 701 ± 66 Ma, which was inferred to provide a minimum age for the metamorphism by Olszewski et al. (1981), however $^{40}Ar/^{39}Ar$ plateau ages on hornblende and mica have given ca. 495 Ma ages for the Kellys Mountain Plutonic Complex and its contact aureole (Keppie and Dallmeyer 1989a). The Pleasant Bay Complex underlies large areas in the western Cape Breton Highlands and is made up of biotite gneiss, amphibolitic gneiss, gneissic granodiorite, marble, quartzite and schist cut by lit-par-lit gneiss (Currie 1987). A syenite intrusive into gneisses of the Pollets Cove Brook Group (= Pleas-

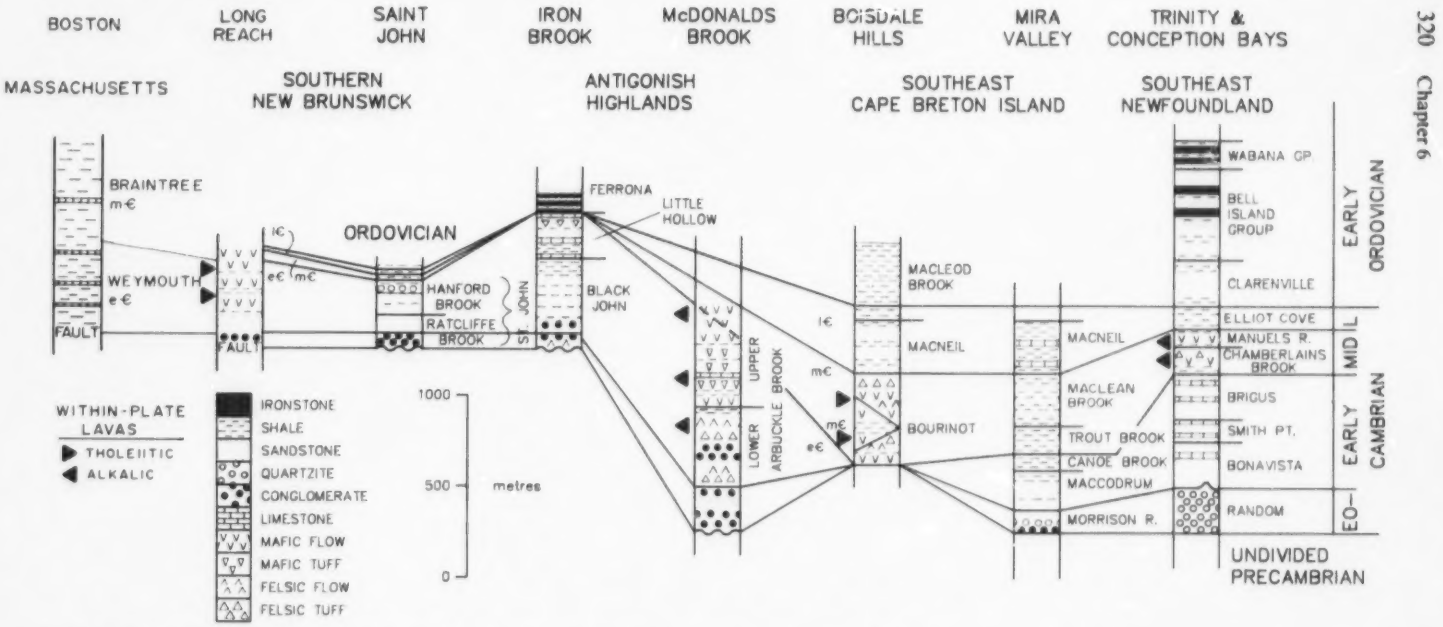

Fig. 3. Cambrian-Ordovician lithostratigraphy of the Avalon Composite Terrane in the northern Appalachians

ant Bay Complex) in northern Cape Breton Island has yielded an U-Pb chord with lower intercept age of $918+78-179$ Ma and an upper intercept age of $1172+135-73$ Ma (Barr et al. 1987). Using these data, Barr et al. (1987) estimated the age of amphibolite metamorphism to be $1040+40-10$ Ma, although it is unclear how this estimate was derived. An alternative interpretation would have the upper intercept as the time of intrusion and the lower intercept as the time of metamorphism. The abraded suite of zircons lies towards the top end of the chord, suggesting that it is projecting toward the time of intrusion, while the euhedral shape of core of the zircons is consistent with an igneous origin. The lower intercept would then represent a minimum age for the high grade metamorphism and deformation.

While more reliable geochronological data are essential, existing data in the Avalon Composite Terrane tentatively suggest that a metamorphic event took place around the Middle-Late Proterozoic boundary.

The next lithostratigraphic unit (Fig. 2) is represented by strongly deformed, miogeoclinal metasedimentary rocks: quartzite, carbonates, greywacke and slate ($\pm$ metavolcanic rocks) of the McMillan Flowage Formation and George River and Cape North Groups (Cape Breton Island), Gamble Brook Formation (Cobequid Highlands), Green Head (New Brunswick), parts of North Haven - Ogier Point-Isleboro - Coombs - Rockport - Ellesworth Formations (southern Maine) and the Blackstone Group and Westboro Formation (southeastern New England). In most places the contact between the gneisses and the metasediments is tectonic. Stomatolites occur in the Green Head Group and were assigned a Middle Riphean age by Hofmann (1974), which is poorly dated but would tentatively correspond to ca. 1000 ± 200 Ma. The close lithological similarities between the George River Group, the McMillan Flowage Formation and the Cape North Group suggest that they are direct correlatives (Keppie 1979). On the other hand, Barr and Raeside (1986), based upon correlations with Newfoundland, argued that the George River Group was Precambrian, while the McMillan Flowage and Cape North Group were Paleozoic. However, the McMillan Flowage Formation has been intruded by several plutons which have yielded 550–570 Ma U-Pb ages (Barr et al. 1988), thereby strengthening the lithostratigraphic correlation of the McMillan Flowage Formation with the George River Group. If this correlation is correct, then these Precambrian metasediments may be traced across the terrane boundary between the Bras d'Or and Highlands Terranes as defined by Barr and Raeside (1986), which are therefore acquitted of being separate terranes. In southern New Brunswick, the contact between the Green Head Group and the Martinon Formation is not exposed, but it is inferred to be an unconformity because slump breccia with fragments of the Green Head Group occur in the Martinon Formation. This breccia is overlain by turbiditic sandstone, siltstone and black chert (Leavitt 1963).

The rest of the Late Proterozoic rocks of the Avalon Composite Terrane are characterized by volcanic rocks and clastic metasediments (Figs. 2, 3). The age of these units is best defined in Newfoundland; elsewhere precise geochronology is generally lacking.

The oldest volcanic rocks occur in the Burin Group of Newfoundland where they are dominated by ophiolitic, mafic lavas and pyroclastic rocks with minor limestone, turbidites, slate, black chert and olistostromal breccia intruded by cogenetic dykes and a sill dated at 763 ± 2 Ma (U-Pb on zircon, Krogh et al. 1988). The Burin Group is a fault-bounded slice which pinches out northwards in the Paradise Sound fault. This fault has suffered Paleozoic movements which complicate the determination of the time of accretion. However, an upper limit is provided by the Rock Harbour Group which unconformably overlies the Burin Group and is correlated with the overstepping, latest Proterozoic Musgravetown Group (Hiscott 1981; Krogh et al. 1988).

Unfortunately, rocks of the same age as the Burin Group are not exposed elsewhere in the Avalon Composite Terrane. However, the geochemistry of the younger Late Proterozoic igneous rocks indicates that they were developed on continental crust (Krogh et al. 1988). This contrasts with the ophiolitic nature of the Burin Group and forms the basis for separating eastern Newfoundland into three Late Proterozoic terranes. Where the Burin Group pinches out, the Paradise Sound fault becomes either a cryptic suture or is cut out by later faulting, which appears to separate a magmatic arc terrane on the west from a cratonic, rifted basin on the east. Correlation of the latest Proterozoic alluvial rocks (Musgravetown - Signal Hill - Rock Harbour Groups) and overlying Cambro-Ordovician platformal sequences across the Paradise Sound fault implies that they represent an overstep sequence across the three terranes in eastern Newfoundland.

West of the Paradise Sound fault, the Fortune Terrane consists of the Marystown-Love Cove

Groups in the east and the Connaigre Bay and Long Harbour Groups in the west. The Marystown-Love Cove Groups are composed of subaerial volcanic rocks which evolved from bimodal and calc-alkaline or tholeiitic flood basalt to predominantly felsic rocks (Krogh et al. 1988). The Marystown Group has been dated at $608 + 20 - 7$ Ma using U-Pb on zircon from an ash-flow tuff (Krogh et al. 1988). The Connaigre Bay and Long Harbour Groups are lithologically similar to the lower and upper parts of the Marystown Group respectively. The Long Harbour Group is overlain by peralkaline rhyolite correlated with those of the Musgravetown Group and followed by platform Cambro-Ordovician rocks (Krogh et al. 1988).

East of the Paradise Sound fault, the Conception Terrane is characterized by the following succession: (1) bimodal, metaluminous flows and pyroclastic rocks with alkaline-tholeiitic, within-plate affinities of the Harbour Main Group with ages in the range 584–635 Ma (Nixon and Papezik 1979; Cameron and Papezik 1983; U-Pb zircon; Krogh et al. 1988); (2) thick northerly-derived turbidites of the Conception and Connecting Point Groups, containing an interbedded tillite near the base of the unit and Upper Riphean-Vendian metazoan fossils near the top; and (3) prodeltaic sandstone and shale of the St. Johns Group. These are overlain, locally with unconformity, by (4) alluvial deposits of the Musgravetown and Signal Hill Groups; and by (5) a Cambro-Ordovician platform sequence (O'Brien et al. 1983).

Late Proterozoic rocks (Fourchu Group and equivalents) are exposed in southern Cape Breton Island, where they are primarily composed of volcanic arc flows and pyroclastic rocks, which are interbedded with subaerial-submarine sediments (Keppie et al. 1979; Dostal et al., 1990). Farther north in Cape Breton Island, volcanic equivalents of the Fourchu Group are only preserved as outliers. However, correlatives exist in the calc-alkaline plutonic roots to the volcanic edifice (Barr et al. 1988). In southern Cape Breton Island, the Late Proterozoic rocks are overlain by Cambro-Ordovician platform rocks. Elsewhere in Cape Breton Island, Cambro-Ordovician rocks are absent. However, Precambrian rocks in the Cape Breton Highlands are overlain by Ordovician-Silurian bimodal, volcanic and sedimentary rocks. Unfortunately, fossils have not been recovered from these rocks. However, pebbles in the Lower Carboniferous Horton Group surrounding the Mabou Highlands contain Cambro-Ordovician and Siluro-Devonian fauna typical of the Avalon Composite Terrane (Norman 1935; Keppie, unpubl. data). Current directions and other pebble lithologies indicate derivation from the Mabou Highlands, suggesting the former presence of the overstep sequence across the Avalon Composite Terrane.

Late Proterozoic rocks in the Antigonish and Cobequid Highlands (Georgeville and Jeffers Groups, Folly River and Warwick Mountain Formations) consist of bimodal, calc-alkaline and tholeiitic rocks overlain by a thick succession of proximal to distal turbidites (Murphy and Keppie 1987; Pe-Piper and Piper 1987; Murphy et al. 1990). In the Antigonish Highlands, the Cambro-Ordovician platformal units rest unconformably upon deformed Precambrian rocks and are, in turn, unconformably overlain by a Siluro-Devonian succession, which are typical of the Avalonian overstep sequence. In the Cobequid Highlands, only the Siluro-Devonian overstep sequence is preserved.

In southern New Brunswick, the Late Proterozoic Coldbrook Group comprises volcanic arc lava, pyroclastic rocks, volcanogenic conglomerate and sandstone intruded in the north by the 10-km-wide and 200-km-long Kingston dyke complex of calc-alkaline to tholeiitic affinity (Giles and Ruitenberg 1977; Currie 1984; Dickson 1985). Equivalent rocks in southern Maine may be present in the Ellsworth and Columbia Falls Formations (Osberg et al. 1985). The Coldbrook Group is overlain by a platformal Eocambrian-Cambrian-Ordovician overstep sequence; lithostratigraphically similar rocks (Megunticook Formation) in southern Maine are unfossiliferous (Osberg et al. 1985). Isolated Precambrian rocks are exposed north of the Belleisle-Lubec fault, and Siluro-Devonian rocks similar to those overstepping the Avalon Composite Terrane elsewhere suggest that Avalonian rocks extend as far north as the Honeydale-Turtle Head fault (Keppie 1985, 1988).

The latest Proterozoic-Early Paleozoic succession in southeastern New England consists of: (1) bimodal, transitional alkalic volcanic rocks of the Middlesex Fells Complex (Durfee Cordoza et al. 1990); overlain by (2) intermediate-felsic, calc-alkaline flows and pyroclastic rocks of the Lynn and Mattapan complexes which have yielded an U-Pb zircon age of 602 ± 3 Ma (Kaye and Zartman 1980; Smith and Hon 1984; Hermes and Murray 1990). These are faulted against (3) the Boston Bay Group, a thick unit of glaciomarine, turbiditic conglomerate, sandstone and argillite containing Vendian acritarchs (Lenk et al. 1982; Socci and Smith 1987); which is followed by (4) Lower-Middle Cambrian shale, siltstone and minor limestone containing

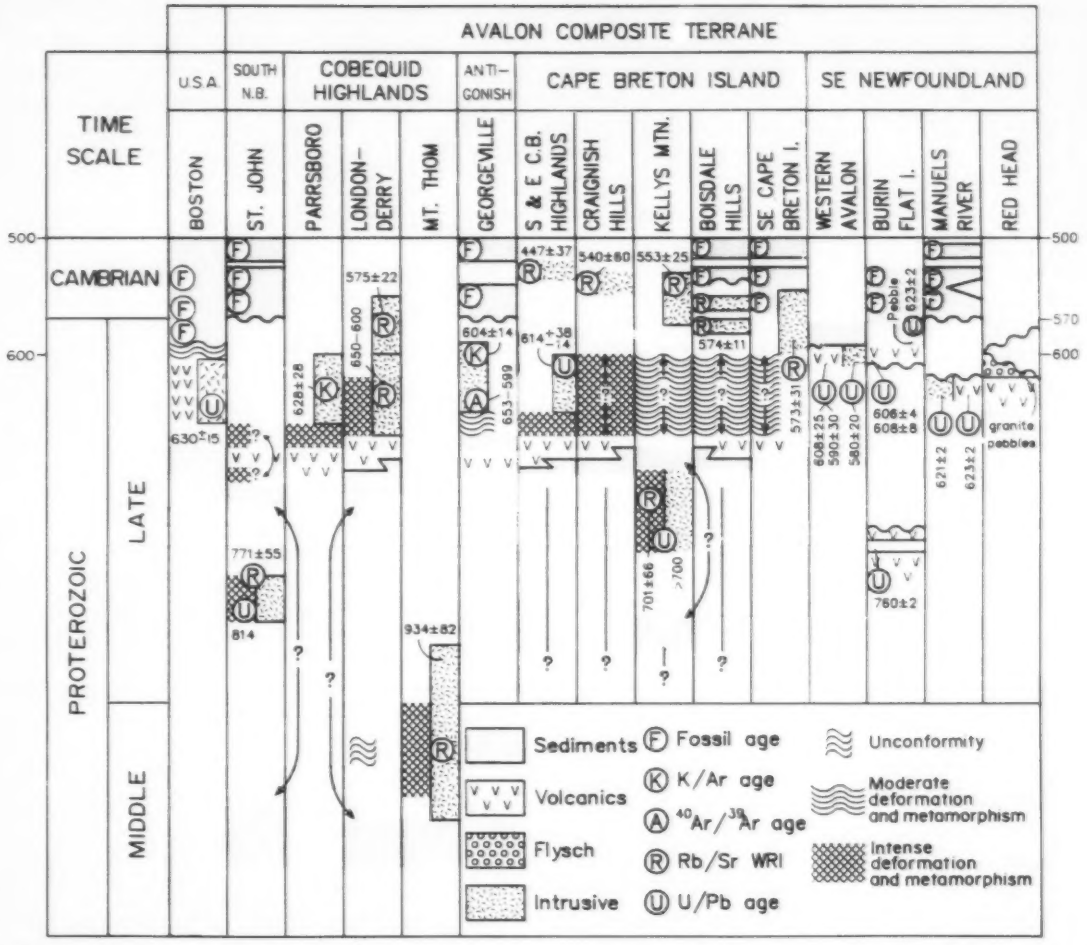

Fig. 4. Constraints on the times of deformation and metamorphism in the Avalon Composite Terrane in the northern Appalachians. *Boston* Volcanic clasts with a predepositional mild deformation occur in the Boston Bay Group; *St. John* deformed clasts of Coldbrook and Green Head Groups occur in the Early Cambrian conglomerates; *Parrsboro* polyphase deformation at greenschist facies metamorphism in Jeffers Formation is cut by Jeffers Brook pluton dated at 628 ± 28 and 616 ± 22 Ma (K-Ar on hornblende; Wanless et al. 1973; dates recalculated by Keppie and Smith 1978), and dated at 605–607 Ma by $^{40}Ar/^{39}Ar$ plateau ages on hornblende (Keppie et al. 1989); *Londonderry* polyphase deformation at greenschist facies metamorphism in Folly River Formation is cut by McCallum Settlement pluton (575 ± 22 Ma, Rb-Sr whole-rock isochron; Gaudette et al. 1983, 1984), Debert River pluton (596 ± 70 Ma, Rb-Sr whole-rock isochron; Donohoe et al. 1986), and Frog Lake pluton (622 ± 3 Ma, $^{40}Ar/^{39}Ar$ plateau age on hornblende; Keppie et al. 1989); *Mt. Thom* polyphase deformation at amphibolite facies metamorphism dated at 934 ± 82 Ma by Rb-Sr whole-rock isochron (Gaudette et al. 1984); *Georgeville* polyphase deformation at greenschist facies metamorphism in Georgeville Group cut by Greendale pluton dated at 604 ± 14 (K-Ar on muscovite, R. K. Wanless, pers. commun.) and 611 ± 3 and 620 ± 5 Ma ($^{40}Ar/^{39}Ar$ plateau ages on hornblende; Keppie et al. 1989), unconformably overlain by Early Cambrian rocks; *Boisdale Hills* polyphase deformation at greenschist facies metamorphism cut by Shunacadie pluton (574 ± 11 Ma Rb-Sr whole-rock isochron; Poole 1980) and Boisdale Hills pluton (563 ± 31 Ma Rb-Sr whole-rock isochron; Cormier 1972; date recalculated by Keppie and Smith 1978; ca. 527–535 Ma $^{40}Ar/^{39}Ar$ plateau ages on hornblende; Keppie et al. 1989); *Southeastern Cape Breton Island* single phase of deformation at greenschist facies metamorphism in Fourchu Group cut by plutons dated between 548 ± 18 Ma and 573 ± 130 Ma (Rb-Sr whole-rock isochrons, Cormier 1972; dates recalculated by Keppie and Smith 1978; Cormier 1980), and between ca. 608–630 Ma ($^{40}Ar/^{39}Ar$ plateau ages on hornblende; Keppie et al. 1989), overlain by Cambrian rocks containing deformed pebbles; *Southeastern Newfoundland* Lower Cambrian rocks rest disconformably to unconformably and nonconformably upon various Precambrian units, while other local unconformities occur at several stratigraphic levels

Acado-Baltic trilobites (Skehan 1983); and (5) Upper Silurian-Lower Devonian volcanic and sedimentary rocks of the Newbury Basin. Close lithostratigraphic correlations between these Early Paleozoic rocks and the Avalon overstep sequence suggest they were formerly continuous with one another.

The Meguma Terrane is characterized by turbidites of the Cambro-Ordovician Meguma Group, which distinguishes it from the platformal overstep sequence in the Avalon Composite Terrane (Keppie 1985, 1988). Constraints on its age are provided by the youngest detrital titanite (560 ± 5 Ma; Keppie and Krogh 1987) and Tremadocian graptolites in the upper unit (Keppie 1985, 1988). This unit is overlain by Late Ordovician-Early Devonian shallow marine to subaerial sedimentary and volcanic rocks, the youngest of which contain the Rhenish-Bohemian fauna also common to the Avalon Composite Terrane (Boucot 1960). This sequence is unconformably overlain by predominantly terrestrial Carboniferous rocks, which overstep the boundary with the Avalon Composite Terrane.

3 Structure and Metamorphism

3.1 Middle-Late Proterozoic Tectonothermal Event

The times and intensity of deformation and metamorphism are summarized in Fig. 4. The oldest tectonothermal event is recorded in the oldest gneissic units in the Avalon Composite Terrane. In southern Cape Breton Island, the Kellys Mountain Complex displays folds in the gneissic banding with a parallel foliation (Jamieson 1984; Keppie et al. 1985). A 701 ± 66 Ma Rb-Sr whole-rock isochron from these gneisses was interpreted as the time of metamorphism by Olszewski et al. (1981). However, a low-pressure, upper amphibolite facies metamorphism including anatexis produced in the contact aureole of the Kellys Mountain Plutonic Complex postdates the gneissic foliation. Hornblende and mica from both the plutonic complex and its aureole gave ca. 493-498 Ma $^{40}Ar/^{39}Ar$ plateau ages (Keppie and Dallmeyer 1989a). In northwestern Cape Breton Island, the gneiss of the Pleasant Bay Complex displays polyphase deformation and several episodes of metamorphism: the early metamorphism is largely obscured by a high-pressure and high-temperature upper amphibolite (-granulite) facies metamorphism overprinted by late retrograde metamorphism (Currie 1987). As discussed in the previous section, the age of the high-grade metamorphism is inferred to be ca. $918 + 78 - 179$ Ma, rather than the $1045 + 40 - 10$ Ma age estimated by Barr et al. (1987).

In the Cobequid Highlands, gneiss of the Mount Thom Complex exhibits polyphase deformation that produced an early foliation folded by isoclinal folds associated with an axial planar foliation and amphibolite facies metamorphism. This, in turn, is deformed by a crenulation cleavage (Donohoe 1976; Donohoe and Cullen 1983). The poorly defined 934 ± 82 Ma Rb-Sr whole-rock isochron age (Gaudette et al. 1984) may date the high-grade metamorphic event, although isotopic mixing and/or resetting by the last event cannot be ruled out and could account for the large error. Farther west in the Cobequid Highlands, the Great Village River Gneiss is reported to possess early fabrics, developed under amphibolite facies metamorphism, which are truncated by a shear zone forming the boundary of the Gamble Brook Formation (Cullen 1984; Murphy et al. 1988).

In southern New Brunswick, the Brookville Gneiss has been interpreted as either the highly metamorphosed equivalent of the Green Head Group (Wardle 1978), or a basement to the Green Head Gneiss (Currie et al. 1981). Currie et al. (1981) record a more complex structural style and at least two more phases of mafic dyke emplacement in the Brookville Gneiss than occur in the Green Head Group. This suggests that a period of deformation accompanied by upper amphibolite facies metamorphism and anatexis may have occurred in the Brookville Gneiss before deposition of the Green Head Group. As presented in the previous section, geochronological data suggest that this metamorphism took place at least 800 Ma ago.* The polyphase deformation in the Brookville Gneiss occurs as complex small interference patterns formed by roughly coplanar axial planes but variably oriented fold axes in narrow linear zones within more homogeneous gneiss with planar or gently curved to pinch-and-swell gneissosity (Currie et al. 1981).

3.2 Late Proterozoic-Cambrian Tectonothermal Event

Identification of Late Precambrian structures in the Avalon Composite Terrane is still fraught with uncertainties in many areas. This is largely due to a

* see footnotes on p. 329.

combination of factors including a dearth of critical contacts and isotopic data, and the problem of distinguishing Paleozoic from Precambrian-Cambrian structures, especially where Paleozoic deformation is relatively intense, as in northern Cape Breton Island.

The nature of the Late Precambrian tectonothermal event varies considerably. Mild and non-penetrative warping and block faulting, disconformities and unconformities and sub-greenschist facies metamorphism accompany the event in Newfoundland, in the southern parts of the Antigonish Highlands and southern New Brunswick, and in southeastern New England. In contrast, moderate single-phase to intense polyphase deformation and greenschist to amphibolite facies metamorphism accompany the event in Cape Breton Island, in the northern Antigonish Highlands and in the Cobequid Highlands. In southern New Brunswick, Ruitenberg et al. (1979) and McCutcheon (1981) reported deformed clasts of both Green Head and Coldbrook Groups in Lower Cambrian conglomerates. Such inhomogeneous deformation appears to be related to the presence or absence of both steeply and gently dipping shear zones. Few kinematic analyses of these shear zones are presently available, and they give various senses and times of movement.

1. Keppie and Murphy (1988) have inferred that the Cambro-Ordovician rocks in the Antigonish Highlands were deposited in a dextral pull-apart basin which closed in the Ordovician by sinistral movements;
2. The Precambrian structures in the northern Antigonish Highlands are inferred to have resulted from dextral transpression superimposed on early transcurrent movements of unknown sense (Murphy et al. in press);
3. Nance and Murphy (1990) interpret the structures in the Folly River Formation in the Cobequid Highlands in terms of sinistral transtension at ca. 630 Ma followed by dextral transpression at ca. 600 Ma;
4. The oblique north to northeasterly trend of the dykes relative to the axis of the Kingston complex in southern New Brunswick suggests their emplacement accompanied sinistral shear (Leger and Williams 1986): dyke emplacement is considered to have coincided with that of the Eocambrian plutonic suite at 565 ± 8 Ma (U-Pb on zircon) on the basis of their similar Th-rich composition (Currie 1988);**
5. Dextral Late Proterozoic movements on the Weston and Bloody Bluff faults in southeastern New England have been postulated by Nelson (1976) and Barosh (1984).

Clearly, more kinematic studies combined with geochronology are required before any regional conclusions can be drawn.

4 Igneous Activity

The geochemistry of the volcanic and plutonic rocks of the Avalon Composite Terrane is summarized in Figs. 1 and 2. The oldest volcanic rocks occur only in the fault-bounded Burin Group of Newfoundland dated at 763 ± 2 Ma (U-Pb on zircon; Krogh et al. 1988). Strong et al. (1978) and Strong and Dostal (1980) have shown that the submarine basalt of the Burin Group evolved from alkaline to oceanic tholeiites.

The oldest rocks exposed in the Conception Terrane occur in the Harbour Main Group, which is cut into three lithologically distinct blocks by faults (O'Brien and King 1982). From west to east the fault blocks consist of: (1) ash-flow tuff, basalt and volcaniclastic sediments with an ignimbrite dated at 606 ± 4 Ma and a rhyolite dated at 623 ± 2 Ma (U-Pb on zircon; Krogh et al. 1988); (2) felsic and mafic pyroclastic rocks intruded by comagmatic Holyrood granite dated at 621 ± 2 Ma and a rhyolitic porphyry dated at 631 ± 2 Ma (U-Pb on zircon; Krogh et al. 1988); and (3) pillow lava and aquagene tuff intruded by a porphyritic rhyolite dyke dated at 586 ± 3 Ma (Krogh et al. 1988). Geochemically most of these rocks are alkaline with metaluminous affinities, although the Holyrood pluton displays calc-alkaline characteristics (Nixon and Papezik 1979; Cameron and Papezik 1983).

The oldest rocks in the Fortune Terrane occur in the lower parts of the Love Cove (dated at 590 ± 30 Ma U-Pb on zircon; Dallmeyer et al. 1981b) and Marystown Groups and in the Connaigre Bay Group. Generally, they consist of subaerial flows and pyroclastic rocks of mafic, intermediate and felsic composition showing calc-alkaline - tholeiitic affinities (Strong et al. 1978; O'Brien et al. 1983; O'Brien et al. 1984). An ignimbrite from the Marystown Group gave an age of $608 + 20 - 7$ Ma (Krogh et al. 1988). These rocks are intruded by comagmatic calc-alkaline plutons, one of which has yielded a U-Pb age of $557 + 29 - 16$ Ma (recalculated by Krogh et al. 1988 from Dallmeyer et al. 1981b), $^{40}Ar/^{39}Ar$ plateau ages on hornblende of 560 ± 15

** see footnotes on p. 329.

and 566 ± 15 Ma, and a Rb-Sr whole-rock isochron of 548 ± 11 Ma (Dallmeyer et al. 1981b).

These rocks are overstepped by the Musgravetown Group and its correlatives, which contain some volcanic rocks. In the Bull Arm Formation, the volcanic rocks consist mainly of bimodal lavas and pyroclastic rocks with alkaline affinities (Hughes and Malpas 1971). In the Long Harbour Group and the upper part of the Marystown Group, the volcanic rocks are flood basalt and peralkaline rhyolite (O'Brien 1987). Volcanism in the overlying Cambrian rocks is bimodal, within-plate and alkalic (Greenough and Papezik 1985). Some peralkaline plutons in the Avalon Composite Terrane may be subvolcanic equivalents of these latter suites of volcanic rocks (Tuach 1984; O'Brien 1987). Thus, the igneous rocks of the Fortune and Conception Terranes evolved from calc-alkaline and metaluminous-alkaline in the Late Proterozoic (625–560 Ma) to alkaline in the latest Proterozoic and Cambrian. The geochemistry of these rocks may be interpreted in terms of a Late Proterozoic rifted magmatic arc followed by latest Proterozoic-Cambrian within-plate rifting.

Late Proterozoic volcanic rocks in southern Cape Breton Island occur in several fault blocks. In most of the blocks they are predominantly subaerial-submarine, mafic-intermediate-felsic lavas and pyroclastic rocks with volcanic arc affinities (Keppie et al. 1979; Zhai et al. 1987). One of the blocks contains a massive sulphide deposit that is associated with rhyolite showing a distinctive, nearly flat rare earth pattern and a negative Eu anomaly. These volcanics are associated with hornblende-biotite, I-type, epizonal, calc-alkaline diorite, tonalite and granite (Barr et al. 1982) giving ages in the range of ca. 615–515 Ma (Rb-Sr whole-rock isochrons; Keppie and Smith 1978) and ca. 630–600 Ma ($^{40}Ar/^{39}Ar$ plateau ages on hornblende; Keppie et al. 1989). Farther north in Cape Breton Island the volcanic rocks have been eroded away; however, the calc-alkaline plutons are preserved (Barr et al. 1982, 1988). Cambrian volcanic rocks are typically tholeiitic, bimodal and within-plate (Murphy et al. 1985). Thus, igneous activity changed from magmatic arc in the Late Proterozoic to within-plate, rift-related in the Cambrian.

In the Antigonish and Cobequid Highlands of Nova Scotia, the Late Proterozoic volcanic rocks are made up of two suites which, in places, are interbedded: (1) bimodal, porphyritic and calc-alkaline; and (2) bimodal, aphyric, continental tholeiites (Murphy et al. 1990, in press). These volcanic rocks are interpreted to have been extruded in an intra-arc rift basin. Associated plutonism is mainly gabbroic-dioritic and has a calc-alkaline geochemistry, and has yielded $^{40}Ar/^{39}Ar$ plateau ages on hornblende of ca. 630–600 Ma (Keppie et al. 1989). Early Cambrian volcanic rocks are bimodal, subaerial to submarine, and have alkalic, within-plate, geochemical characteristics (Murphy et al. 1985). Thus, these areas show a change from mixed, calc-alkaline and tholeiitic, intra-arc rifting in the late Proterozoic to alkalic and within-plate, rift-related in the Cambrian.

In southern New Brunswick, late Proterozoic volcanic rocks have been assigned to the Coldbrook Group, which comprises a thick sequence of mafic-intermediate-felsic lava, felsic tuff, lahar, volcanic breccia and volcanogenic sediments (Giles and Ruitenberg 1977). The mafic lava has a volcanic arc geochemistry (our unpublished data). Associated plutonism shows a diverse range of composition from gabbro, through hornblende diorite, tonalite, granodiorite, quartz monzonite to granite (Ruitenberg et al. 1979; Currie et al. 1981). Age dates are limited to 625 ± 15 Ma (U-Pb on zircon from the Cape Spencer granite; Watters 1987), 598 ± 18 Ma (Rb-Sr whole-rock isochron from the Fortyfive River granodiorite; Barr 1987), 530 ± 16 Ma (Rb-Sr whole-rock isochron on the Bonnell Brook pluton; McLeod 1986) and 598 ± 17 Ma (K-Ar on hornblende from the Alma diorite; Barr 1987). Eo-Middle Cambrian volcanic rocks are bimodal, subaerial, tholeiitic and related to within-plate rifting (Greenough et al. 1985). Thus, Late Proterozoic magmatic arc igneous activity gave way to tholeiitic, within-plate, rift-related magmatism in the Cambrian.

In southeastern New England, Late Proterozoic volcanic rocks occur in the Middlesex Fells, Lynn and Mattapan Complexes. The older Middlesex Fells Complex contains bimodal volcanic rocks, the mafic members of which are transitional alkali olivine basalt (Durfee Cordoza et al. 1990). The Lynn-Mattapan Complexes consist of felsic pyroclastic rocks, lahar, volcanic breccia and andesite (Smith and Hon 1984; Hermes and Murray 1990; Thompson and Hermes 1990), which have been dated at 602 ± 3 Ma (Kaye and Zartman 1980). These latter complexes are slightly younger than the neighbouring plutons: (1) the calc-alkaline Dedham diorite-tonalite-granodiorite-granite has yielded an U-Pb, upper intercept age of 630 ± 15 Ma (Zartman and Naylor 1984) and a Rb-Sr whole-rock isochron age of 595 ± 16 Ma (Kovach et al. 1977); and (2) the calc-alkaline, Esmond, gabbro-granite pluton that gave an U-Pb, upper intercept age of 621 ± 8 Ma

(Hermes and Zartman 1985). Thus, the Late Proterozoic igneous rocks of New England evolved from alkaline, rift-related to calc-alkaline, magmatic arc.

5 Possible Correlatives

In southern Newfoundland, south of the Bay d'Est-Dragon Bay Fault zone (Fig. 1), a belt of rocks (Burgeo Terrane) occurs that has affinities with the Avalon Composite Terrane (O'Brien et al. 1986, 1989; Keppie and Dallmeyer 1989a). This coastal belt consists of paragneiss, orthogneiss ($686+33/-15$ Ma, U-Pb zircon age; O'Brien et al. 1989), migmatite and amphibolitic gneiss (Grey River and Cinq Cerf Gneiss) that were (1) polydeformed and metamorphosed under amphibolite facies conditions at 579 ± 10 Ma (U-Pb zircon age; O'Brien et al. 1989); (2) intruded by the Roti granite at 563 ± 4 Ma (Dunning et al. 1988); (3) unconformably (?) overlain by low grade metasedimentary and metavolcanic rocks yielding magmatic zircon of 544 ± 5 Ma age and detrital zircon of ca. 593 Ma age (O'Brien et al. 1989); (4) unconformably overlain by a thick volcanosedimentary sequence (La Poile Group) that yielded U-Pb ages between $420+8/-2$ and 428 ± 5 Ma that may be extrusive equivalents of the Burgeo pluton dated at $429+5/-3$ Ma (foliated granite) and 415 ± 2 Ma (weakly foliated granite), and the strongly foliated to mylonitic Gaultois pluton dated at 422 ± 2 Ma (U-Pb zircon age, Dunning et al. 1988; O'Brien et al. 1986); and (5) post-tectonically intruded by the Chetwynd pluton (377 ± 20 Ma, U-Pb zircon age and 372 ± 5 Ma, $^{40}Ar/^{39}Ar$ biotite age; Dallmeyer 1980; Chorlton and Dallmeyer 1986) and the undated Francois pluton. Although the Burgeo Terrane lacks the Avalonian, Cambro-Ordovician overstep sequence, the La Poile Group may be equivalent to the Ordovician-Silurian volcanosedimentary sequence occurring in the Cape Breton Highlands of Nova Scotia. The older units, Late Proterozoic volcanic and sedimentary rocks and older gneisses, are comparable in both the Burgeo Terrane and the Cape Breton Highlands.

Deformation of the La Poile Group took place under greenschist facies metamorphic conditions and varies from a weakly developed fracture cleavage associated with open folds in the east to polyphase deformation involving coaxial folds associated with a slaty cleavage overprinted by a crenulation cleavage followed by cross folds (Chorlton 1980; O'Brien 1988). The two dated phases of the Burgeo pluton bracket the earliest foliation in the La Poile Group, while the Chetwynd pluton provides an upper age limit on the later phases; i.e. Middle Silurian to Middle Devonian. This deformation is inferred to be associated with docking and accretion of the Burgeo Terrane to the Newfoundland Gander Terrane, and the Burgeo pluton stitches the Bay d'Est-Dragon Bay Fault boundary between the two terranes.

6 Geophysics

6.1 Magnetic, Gravity and Seismic Data

The Avalon Composite Terrane is generally characterized by positive magnetic anomalies (up to 700 gammas) and positive free air gravity anomalies (up to 70 mGals) which contrast with the negative anomalies over the Devono-Carboniferous basins and the Meguma Terrane (Williams and Haworth 1984a, b). Within the Avalon Composite Terrane of Newfoundland, arcuate zones of positive magnetic and gravity anomalies may be correlated with outcrop belts of volcanic and plutonic igneous rocks, whereas the negative anomalies coincide with exposed sedimentary rocks. These and similar anomalies may be traced in the offshore area to the edge of the continental shelf and as far east as the Flemish Cap. South of Newfoundland, however, they merge with or are truncated by the Collector Anomaly interpreted as the southern edge of the Avalon Composite Terrane (Haworth and Lefort 1979). Similar geophysical features are more obscure over and around the Avalon Composite Terrane of Maritime Canada and New England, because they are partly masked by the effects of Paleozoic rocks. Reflection seismic data acquired north of Newfoundland indicate that the deep structure of the Avalon Composite Terrane is distinct and characterized by discontinuous, arcuate reflectors at ca. 5 and 9–12 seconds two-way travel time separated by transparent regions (Keen et al. 1986). The lower reflective zone probably represents the Moho, but the significance of the upper reflectors is unknown. Refraction seismic data suggest that compressional wave velocities beneath the Avalon Composite Terrane are 6 km/s on top of 7.4 km/s, which contrasts with the calculated velocites beneath the Meguma Terrane of 5.4 km/s above 6.25 km/s (Dainty et al. 1966).

6.2 Paleomagnetic Data

Paleomagnetic data for Late Proterozoic-Early Paleozoic stratified rocks in the Avalon Composite Terrane have yielded the following intermediate paleolatitudes:

1. 34–36° S (±7°) for the Late Proterozoic Marystown Group in Newfoundland, interpreted as primary magnetization (Irving and Strong 1985);
2. 45° S (±6°) for the post-folding magnetization of the Late Proterozoic Fourchu Group in Cape Breton Island, inferred to have been produced by oxidation during erosion following the latest Proterozoic folding (Johnson and Van der Voo 1986);
3. 47–49° S (±11°) for the dual-polarity, pre-folding magnetization of the Middle Cambrian Bourinot Group in Cape Breton Island, deduced to be primary magnetization (Johnson and Van der Voo 1985);
4. 42° S (±5°) for the pre-folding magnetization of the Late Ordovician-Early Silurian Dunn Point Formation in Nova Scotia, inferred as primary magnetization (Van der Voo and Johnson 1985).

Declinations associated with these paleolatitudes are highly variable, an observation which may be related to rotations about a vertical axis. Siluro-Devonian paleolatitudes for the Avalon Composite Terrane and cratonic North America are similar (Miller and Kent 1988). However, Cambro-Ordovician paleolatitudes are different: 45°–50° for the Avalon Composite Terrane and 10°–20° S for eastern North America (Van der Voo 1988). Late Proterozoic-Cambrian paleolatitudes derived for the Avalon Composite Terrane are consistent with a location adjacent to Gondwana or Armorica (Johnson and Van der Voo 1986).

7 Tectonic Interpretation

The stratigraphic and petrological data for the Late Proterozoic rocks of the Avalon Composite Terrane indicate that they were formed in a rifted magmatic arc environment in which active magmatic arc areas alternated with rifted basins. Available data indicate that the rifted basins were floored by continental crust except for the oceanic lithosphere preserved in the Burin Terrane of Newfoundland. The original width of the oceanic Burin Terrane is unknown. Its presence may be interpreted in terms of either (1) the original existence of two arcs or (2) the original presence of one arc subsequently offset by transcurrent faulting to either side of the oceanic terrane. It is also possible that the Late Proterozoic rocks from New England to Cape Breton Island formed in one contiguous magmatic arc. However, gaps in exposure allow the possibility that more than one arc is present. Structural data suggest that opening and closing of the intra-arc rifts took place by transcurrent motions, presumably related to oblique convergence. The polarity of subduction is presently uncertain. The Late Proterozoic magmatic arc rocks were replaced by latest Proterozoic-Cambrian tholeiitic-alkaline, rift-related volcanic rocks. The Cambrian rocks appear to have been deposited in pull-apart basins, suggesting a continuation of the transpressional strike-slip regime operative in the Late Proterozoic.

The geochemistry of the Late Proterozoic igneous rocks indicates that the magmatic arc was built upon continental crust. This crust is only exposed in southern New Brunswick and Nova Scotia, where it consists of a Middle-Late Proterozoic miogeocline resting unconformably upon a gneissic basement. Both of these latter units were deformed and metamorphosed in Middle-Late Proterozoic times before the development of the Late Proterozoic igneous rocks.

Faunal provinciality and paleomagnetic data indicate that the Avalon Composite Terrane had affinities with Gondwana and Armorica during Late Proterozoic-Cambrian times. In a Permian Pangaea A2 reconstruction (Van der Voo et al. 1984), the Avalon Composite Terrane and Meguma Terrane in the northern Appalachians lie adjacent to northwest Africa. Consequently, most correlations have drawn attention to the similarities between the Avalon Composite Terrane and the Pan African orogens of Morocco and the Trans-Saharan belt (e. g. O'Brien et al. 1983), while Schenk (1981) has inferred a source for the Meguma sediments in Morocco. The Bou-Azzer ophiolite in Morocco is the same age as the Burin ophiolitic sequence in Newfoundland, and the Late Proterozoic and Early Paleozoic stratigraphy are comparable. However, in northwest Africa, the Late Proterozoic orogens are built upon Archean and Early Proterozoic rocks, whereas preliminary data suggest that the Avalon Composite Terrane is underlain by Middle-Late Proterozoic basement. Only in South America are Late Proterozoic orogens built upon a Middle-Late Proterozoic basement (Keppie and Dallmeyer 1989b). This continent may therefore represent the provenance of the Avalon Composite Terrane. The synchroneity of Late Proterozoic-Cambrian subduction beneath the Avalon Composite Terrane and the opening of

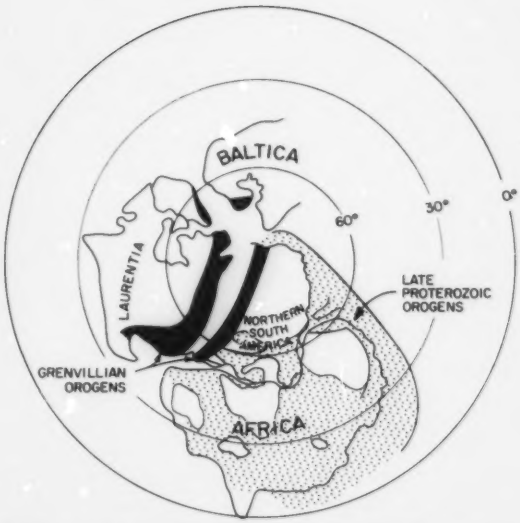

Fig. 5. Latest Precambrian-earliest Cambrian palinspastic reconstruction of the Circum-Atlantic region (modified from Bond et al. 1984) showing the locations of Pan-African (which would include the Avalon Composite Terrane) and Grenvillian orogens

Iapetus implies that the Avalon was not within the Iapetus Ocean. A possible Late Proterozoic-Cambrian reconstruction is shown in Fig. 5. The preservation of the Avalonian magmatic arc sequences contrasts with the general absence of magmatic arc rocks in continent-continent collision orogens, where they were presumably eroded away because they lie on the upper plate. This suggests that the termination of subduction beneath the Avalon Composite Terrane was not due to continental collision, but may have resulted from the relocation of subduction zones into Iapetus as it passed from a passive to an active margin ocean in the Late Cambrian.

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* Recently published geochronology for the Brookville Gneiss indicates: 1) that it contains detrital zircons with minimum ages of 943 ± 3 and 641 ± 3 Ma; 2) that it was intruded by quartz diorite and tonalite c. 600–630 Ma; and 3) was metamorphosed to upper amphibolite facies under low pressures at c. 570–540 Ma. Thus, rather than representing the basement to the Avalon Composite Terrane, the protolith has been inferred to be a temporal equivalent of the late Proterozoic arc sequence metamorphosed at deeper structural levels (Bevier ML, White CE, Barr SM, in press, late Precambrian U-Pb ages for the Brookville Gneiss, southern New Brunswick, and implications for stratigraphy of the Avalon Terrane, Atlantic Geology; Dallmeyer RD, Doig R, Nance RD, Murphy JB, in press, $^{40}Ar/^{39}Ar$ and U-Pb mineral ages from the Brookville Gneiss and Green Head Group: implications for terrane analysis and evolution of Avalonian "basement" in southern New Brunswick. Atlantic Geology).

** Recent U-Pb geochronology reported for the Kingston dyke complex indicates that they were intruded c. 435.5 ± 1.5 Ma and therefore record the sinistral accretion of the Avalon Composite Terrane with rest of the Appalachians (Doig R, Nance RD, Murphy JB, Casseday RP, in press, Evidence for Silurian sinistral accretion of the Avalon composite terrane in Canada. Journal of the Geological Society of London 147).

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